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Effects of mulching and simple irrigation treatments on the growth of agroforestry species for forest and land rehabilitation in Bukit Sultan, Aceh Besar

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Abstract. Forest and land rehabilitation (FLR) plays a crucial role in restoring degraded ecosystems. Agroforestry, which integrates forestry and agricultural crops, is a promising approach as it provides both ecological benefits and economic value. This study evaluated the effects of simple irrigation and mulching treatments on the growth of jackfruit (*Artocarpus heterophyllus*), nutmeg (*Myristica fragrans*), and bitter bean (*Parkia speciosa*) in Bukit Sultan, Aceh Besar, Indonesia. A factorial design was implemented with four treatments: control (T0), simple irrigation (T1), plastic mulch + irrigation (T2), and banana sheath mulch + irrigation (T3). Two-way ANOVA results showed significant effects of treatments, species, and their interactions on plant height ($p < 0.001$). Jackfruit exhibited the highest growth under T1, nutmeg performed better under T0 and T1 without mulching, while bitter bean responded positively to T2 but declined under T3. These findings highlight species-specific responses to water and mulch management, suggesting that adaptive, species-based agroforestry strategies can enhance the success of land rehabilitation programs.

1. Introduction

Forest and land rehabilitation (FLR) is a critical strategy for restoring the ecological, social, and economic functions of degraded landscapes. Effective FLR contributes not only to ecosystem recovery, water provision, and environmental stability, but also to the long-term resilience of socio-ecological systems. Among the diverse restoration approaches, agroforestry has gained recognition as a particularly effective strategy because it integrates forestry species with agricultural or plantation crops. Unlike monoculture systems, agroforestry enhances soil quality, maintains soil moisture, reduces erosion, and generates economic benefits for local communities, thereby fostering stronger community participation and long-term stewardship. The active involvement of local communities is essential, as they serve not only as implementers but also as custodians of restored landscapes.

Despite its advantages, agroforestry systems often face challenges related to water scarcity and interspecific competition, which can limit plant productivity. Previous studies have demonstrated that the application of mulching and simple irrigation can substantially improve water-use efficiency, enhance soil physical properties, and promote seedling growth and survival in various ecosystems,



including degraded drylands [1,7,8,3]. Both organic and synthetic mulches play a crucial role in maintaining soil moisture, reducing surface temperature, minimizing evaporation, and enriching soil organic matter and nutrient availability. Mulching has also been shown to improve root development, enhance soil structure, and stimulate microbial activity essential for ecosystem health (2,8,18). Similarly, simple and regular irrigation practices can enhance photosynthetic rates, support vegetative growth, stabilize soil water balance, and ensure plant survival during dry periods or in marginal lands [1,5,14].

Evidence from earlier research suggests that combining mulching and irrigation yields synergistic benefits, improving both plant growth and resilience in agroforestry systems. These findings are particularly relevant to the context of Bukit Sultan, Aceh Besar, where water limitations and soil degradation pose significant barriers to successful restoration. Consequently, evaluating the effects of mulching and simple irrigation offers a practical and sustainable solution for improving the success of FLR initiatives in this region (1,7,8,3].

2. Materials and methods

2.1. Tools and materials

Field equipment included hoes, measuring tapes, sickles, digital scales, calipers for stem diameter and height measurements, plastic bottles (1.5 L), hoses, buckets, and documentation tools (camera and field notebook). The experimental materials consisted of seedlings of clove (*Syzygium aromaticum*), nutmeg (*Myristica fragrans*), jackfruit (*Artocarpus heterophyllus*), stink bean (*Parkia speciosa*), and pine (*Pinus merkusii*). Compost fertilizer, banana fronds as organic mulch, and clean water were also utilized.

2.2. Study area

The study was conducted in the Community Forest (HKM) of Bukit Sultan, Lam Tanjong Village, Aceh Besar District, Indonesia, covering approximately 1 ha. The site has been designated as an active Forest and Landscape Restoration (FLR) area managed by the local community. Its topographic and ecological conditions provide a representative setting for long-term assessment of forestry seedling performance. The experiment was carried out over six months, from June, 1st 2025 to August 31st 2025. Site preparation involved land clearing, determination of planting points at 5 × 5 m spacing, and construction of seedling storage and water reservoirs. Initial measurements of soil pH, soil temperature, and soil-air moisture were recorded prior to planting. Planting was conducted on 1 June 2025, with seedlings manually placed into prepared holes, each supplied with 0.5 kg of compost, followed by initial irrigation. A simple irrigation system using plastic bottles and hoses was implemented according to treatment design.

2.3. Experimental design

The experiment consists of four treatments: T0 (Control), T1 (Simple irrigation using Aqua drip), T2 (plastic mulch with irrigation), and T3 (organic mulch using banana fronds with irrigation). Each treatment was replicated five times for each of the five species, yielding 5 × 4 × 5 experimental units. Seedling height was recorded as the sole response variable at 21-day intervals over a three-month period. Data were analyzed using analysis of variance (ANOVA) to test treatment effects [Montgomery, 2009]. The statistical model was:

$$Y_{ijk} = \mu + \alpha_i + \beta_j + (\alpha\beta)_{ij} + u_k + \varepsilon_{ijk} \quad (1)$$

Where Y_{ijk} is the observation at the i -th treatment and j -th plant group and k -th week. μ the overall mean, α_i the treatment effect, β_j the plant group effect, $(\alpha\beta)_{ij}$ interaction effect, u_k error of weekly effect k - k and ε_{ij} the error term (Spyroglou et al.; Pagliari et al.). When the F-test indicated significant treatment effects, mean separation was performed using Tukey's Honestly Significant Difference (HSD) at the 5% level [Gomez & Gomez, 1984].

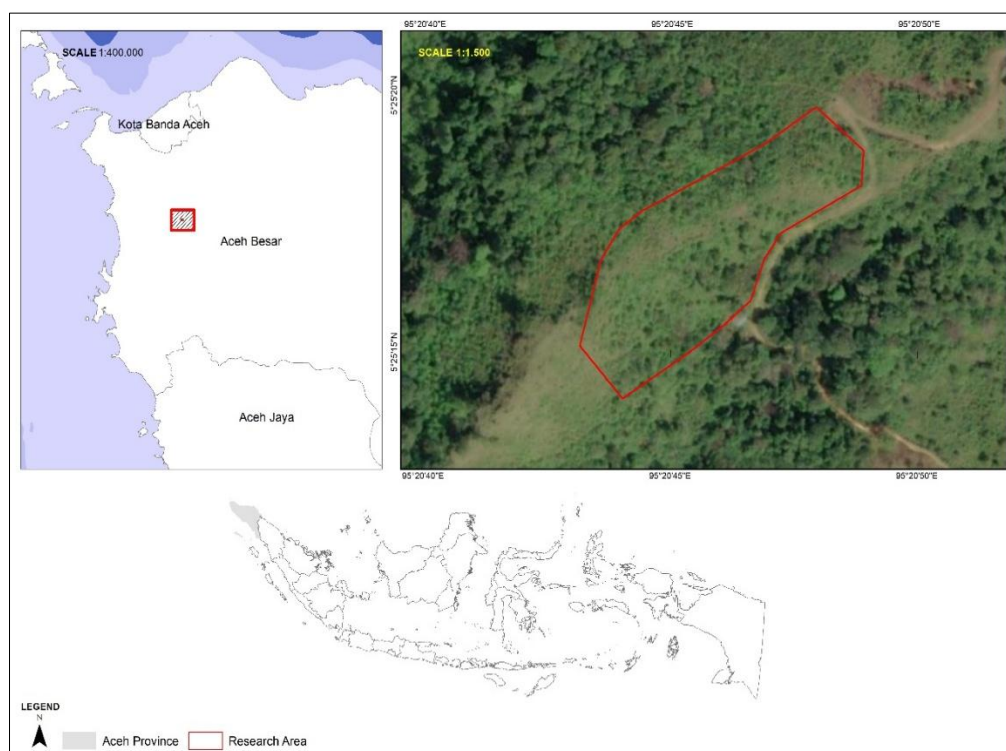


Figure 1. Map of the study site located in the Bukit Sultan Community Forest (HKM), Aceh Besar District

3. Results and discussion

Forest and land rehabilitation interventions are highly dependent on the suitability of the treatment given to the biological and ecological characteristics of the species used. The results of the analysis show that both treatment and species type have a significant effect on plant height, as indicated by the results of the two-way ANOVA test. In addition, the interaction between treatment and species is also statistically significant, indicating that the growth response is not uniform across all plant types.

The figure presents the estimated marginal means (EMMeans) with 95% confidence intervals for three forestry species (Jackfruit, Nutmeg, and Parkia) under four treatments (T0 = Control, T1 = Aqua Drip Irrigation, T2 = Plastic Mulch + Aqua, T3 = Banana Sheath Mulch + Aqua). The response patterns across species show notable contrasts. For Jackfruit, the highest mean growth was observed under T1, followed by a gradual decline under T2 and T3, although still above the control (T0). This suggests that simple irrigation (Aqua Drip) provided the most significant contribution to early growth performance, whereas the addition of mulching did not consistently enhance the outcome. Although jackfruit can tolerate relatively dry conditions, optimal growth is achieved when soil moisture is maintained evenly and continuously [4]. Accordingly, irrigation-based treatments (T1, T2, and T3) proved more advantageous than the absence of intervention (T0). Regular and optimal water supply is crucial for jackfruit growth, particularly during the early developmental phase. Previous studies have demonstrated that irrigation combined with nutrient supplementation (e.g., the addition of nitrogen fertilizer to irrigation water) significantly enhances growth performance and physiological parameters of jackfruit, including plant height, leaf number, and biomass [10,5]. A stable irrigation regime also helps maintain soil moisture, which is critical for achieving optimal growth [1,9].

In contrast, Nutmeg exhibited a decreasing trend with increasing treatment intensity. The highest means were found in T0 and T1, while T2 and T3 showed substantially lower values. This indicates that Nutmeg appears to be more adaptive under natural conditions without mulching, and that excessive mulching might even hinder its growth. At T0, shading played a crucial role by supporting the early

growth phase of nutmeg through partial light exposure instead of full sunlight. Meanwhile, although seedlings under T1 were not shaded, simple irrigation still exerted a positive influence on growth. This can be explained by the shallow root system of nutmeg, which makes it highly susceptible to drought, moisture deficit, and even waterlogging [1]. Thus, regular water availability is a key factor determining optimal nutmeg growth. Modern irrigation systems such as drip irrigation are considered more water-efficient, as they reduce surface water loss compared to surface irrigation, which remains widely used by farmers [1,9]. When applied more broadly, such water-saving irrigation systems not only have the potential to enhance nutmeg growth and productivity but also serve as an effective adaptation strategy to address climate change challenges.

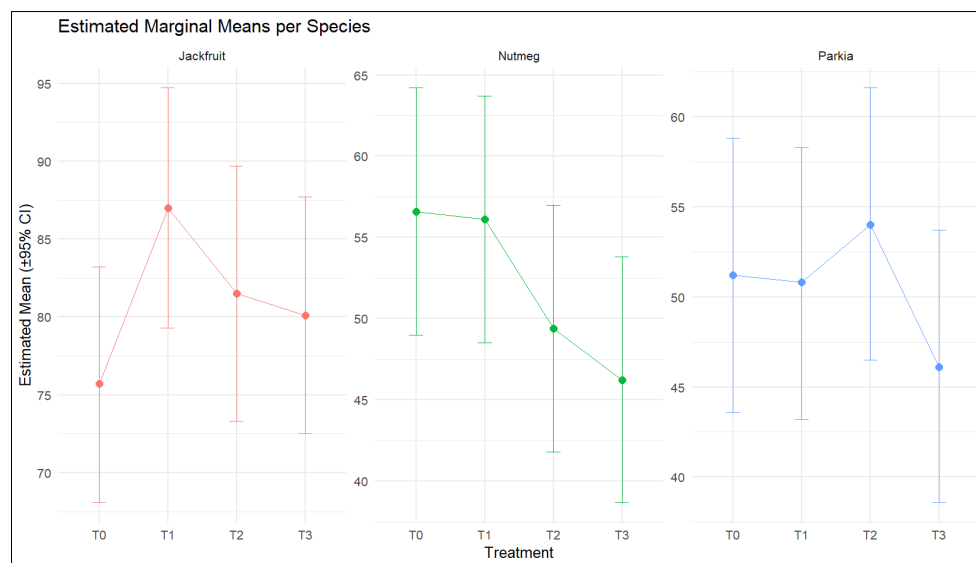


Figure 2. Estimated marginal means by treatment and species (error bars represent standard deviation of mean, n= 412)

Conversely, the reduced growth of nutmeg under mulching treatments (T2 and T3), compared to the control and simple irrigation (T0 and T1), indicates that nutmeg performs better under natural conditions without additional mulching. This result aligns with studies on other crops showing that, while mulching can improve soil moisture and temperature, not all species respond positively. In some plants, excessive mulching may cause excessive moisture retention, reduced soil aeration, and restricted root growth (2). This supports the finding that nutmeg is more adaptive in environments without intensive mulching modifications (T0 under shade, T1 under shade, while T2 and T3 without shade).

For Parkia, the responses were more fluctuating. Means remained relatively stable in T0 and T1, peaked at T2, and then dropped sharply under T3. This pattern implies that plastic mulch combined with simple irrigation (T2) may enhance the early growth of Parkia, whereas organic mulching (T3) did not exert the same positive effect. The Parkia response indicates that combining plastic mulch with irrigation may improve water-use efficiency and support early growth. Research on other crops in dryland systems has shown that plastic mulch enhances soil water retention, improves root distribution, and increases productivity under drought stress [10]. Beyond its role in dry periods, proper drainage management is strongly recommended to address water excess during heavy rainfall [2]. However, the use of organic mulch (T3) does not always deliver comparable effects, possibly due to rapid decomposition or unfavorable shifts in soil microclimate for Parkia growth.

Overall, the estimated means reveal a clear interaction between species and treatments. Jackfruit responded positively to simple irrigation, Nutmeg performed better under natural conditions, and Parkia showed a preference for the plastic mulch–irrigation combination. These variations highlight the

importance of species-specific strategies in forest rehabilitation programs, as the effectiveness of treatments depends on the physiological requirements and ecological adaptations of each species.

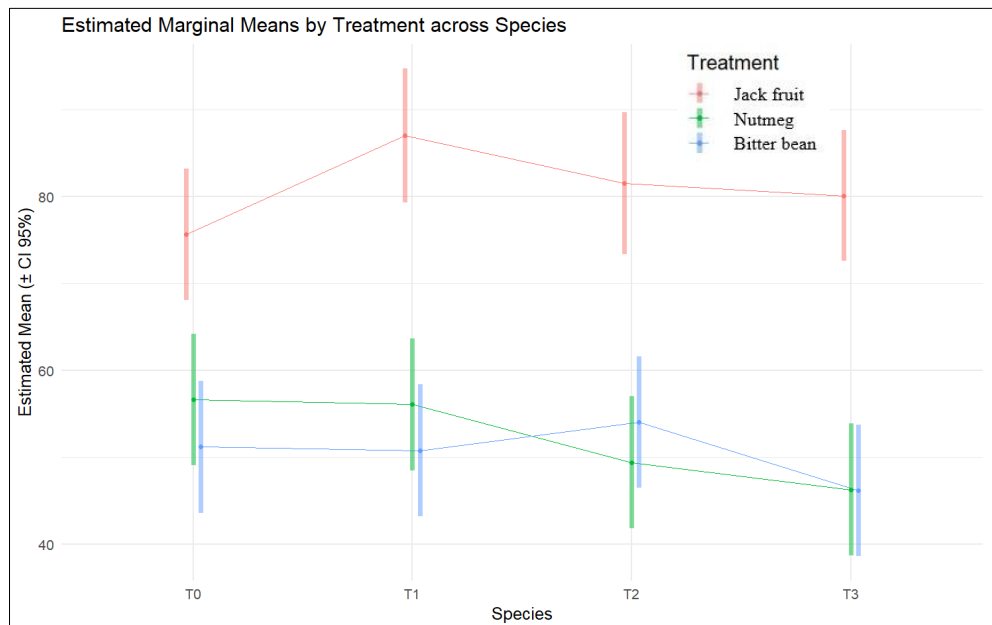


Figure 3. Estimated marginal means by treatment across species (error bars represent standard deviation of mean, $n = 412$)

The figure illustrates the estimated marginal means (EMM) of plant height across three species (jackfruit, nutmeg, and bitter bean) under four treatments (T0–T3), along with their 95% confidence intervals. Overall, the patterns highlight clear differences in growth responses among species, although treatment effects tend to follow consistent trends within each species. Jackfruit exhibited the highest mean growth compared to the other species, with EMM values ranging from approximately 76 to 87. The response curve indicates that treatment T1 (Aqua Drip Irrigation) provided the greatest enhancement in growth, whereas T2 and T3 resulted in slightly lower values but remained above the control. This suggests that jackfruit responds particularly well to simple irrigation, while additional mulching provides limited added benefit.

In contrast, nutmeg showed a gradual decline in growth across treatments, with EMM values ranging from 46 to 57. Both T0 and T1 yielded higher means, while T2 and T3 consistently lowered growth performance. This pattern indicates that nutmeg seedlings may be more adapted to minimal intervention, and excessive treatment with mulch appears less beneficial for early growth. Bitter bean displayed relatively stable responses, with EMM values between 47 and 55. The growth remained close across treatments, although T2 produced a slight improvement, while T3 showed a decline. These results suggest that plastic mulch with irrigation may enhance growth modestly, whereas organic mulching has less consistent effects.

Overall, the relatively higher growth performance of jackfruit compared to the other species is supported by its adaptability to diverse soil conditions, including nutrient-poor soils, provided that adequate fertilization and maintenance are applied [6]. Jackfruit has also been recognized as a potential species for the reclamation of post-coal mining sites, given that its seeds are relatively capable of germinating and establishing under extreme conditions [12]. Beyond its role in restoration and reclamation, the development prospects of jackfruit have been promoted since 1986 through the Social Forestry Program under an agroforestry scheme, aiming to enhance productivity while ensuring forest sustainability [6]. Taken together, the figure points to a potential interaction between species and treatment. Jackfruit responds most favorably to irrigation, nutmeg benefits from minimal intervention,

and bitter bean shows slight gains under plastic mulching. These findings emphasize the importance of tailoring silvicultural practices to species-specific requirements rather than relying on uniform management strategies in restoration programs.

3.1. Anova

The figure presents the estimated marginal means (EMM) of plant height for jackfruit, nutmeg, and bitter bean under four treatments (T0–T3), accompanied by their 95% confidence intervals. The two-way Anova results (table 1) revealed that both treatment and species significantly influenced growth performance. The main effect of treatment was significant ($F = 6.61$, $p < 0.001$), demonstrating that management interventions altered seedling height. Likewise, the species effect was highly significant ($F = 264.88$, $p < 2.2 \times 10^{-16}$), confirming that species identity constituted the strongest determinant of growth variation.

Table 1. Analysis of variance

Source	Sum Sq	Mean Sq	df	F-Value	P-Value
Treatments	1256	418.7	3	6.6105	0.0002882***
Types	33558	16779.0	2	264.8811	< 2.2e-16 ***
Treatments; Types	1806	300.9	6	4.7505	0.0001584***

Importantly, a significant treatment $\times$ species interaction was detected ($F = 4.75$, $p < 0.001$), indicating that the effectiveness of treatments was not consistent across species. For jackfruit, treatment T1 yielded the highest growth response, surpassing both the control and mulching-based interventions, while T2 and T3 maintained moderately elevated but lower gains. In contrast, nutmeg displayed an opposite trajectory, where the control (T0) and T1 produced relatively higher means, whereas mulching treatments (T2 and T3) resulted in pronounced declines. Bitter bean exhibited a more stable response, with means clustered closely across treatments, although T2 conferred a modest advantage compared to other interventions. These patterns underscore the context-dependent role of management interventions, where treatment benefits are maximized in jackfruit, neutral or even detrimental in nutmeg, and marginal in bitter bean. Collectively, the interaction effect highlights that restoration strategies must be tailored to species-specific growth dynamics rather than applied uniformly across taxa.

3.2. Tuckey test

The two-way ANOVA demonstrated that both treatment and species had significant effects on plant height (table 1). The treatment main effect was significant ($F = 6.61$, $p < 0.001$), indicating that growth performance varied across the management interventions. The species effect was even more pronounced ($F = 264.88$, $p < 2.2 \times 10^{-16}$), confirming that species identity was the dominant determinant of growth variation. Moreover, the interaction effect between treatment and species was statistically significant ($F = 4.75$, $p < 0.001$), underscoring that treatment responses were not uniform across species.

Estimated marginal means (EMM) comparisons further clarified these patterns. For jackfruit (*Artocarpus heterophyllus*), treatment T1 (87.0 cm) resulted in significantly greater growth compared to T0 (75.7 cm; $p = 0.0008$), while differences among T1–T2 and T1–T3 were not statistically reliable. This indicates that jackfruit consistently benefited from treatment T1, whereas other treatments yielded similar outcomes. In contrast, nutmeg (*Myristica fragrans*) exhibited a more heterogeneous pattern: T0 (56.6 cm) outperformed both T2 (49.4 cm; $p = 0.037$) and T3 (46.2 cm; $p = 0.0008$), suggesting that some interventions negatively affected its growth. For bitter bean (*Parkia speciosa*), most pairwise contrasts were not significant, except for T2–T3 ($p = 0.0106$), where T2 promoted moderately higher growth (54.0 cm vs. 46.1 cm).

The results highlight nuanced interaction: while jackfruit responded positively to T1, nutmeg showed growth suppression under T2 and T3, and bitter bean displayed only modest treatment-specific differences. Such species-dependent responses emphasize the necessity of tailoring restoration strategies to species-specific ecological traits rather than assuming uniform treatment effects across taxa. The Pairwise treatment contrasts by species are shown in table 2.

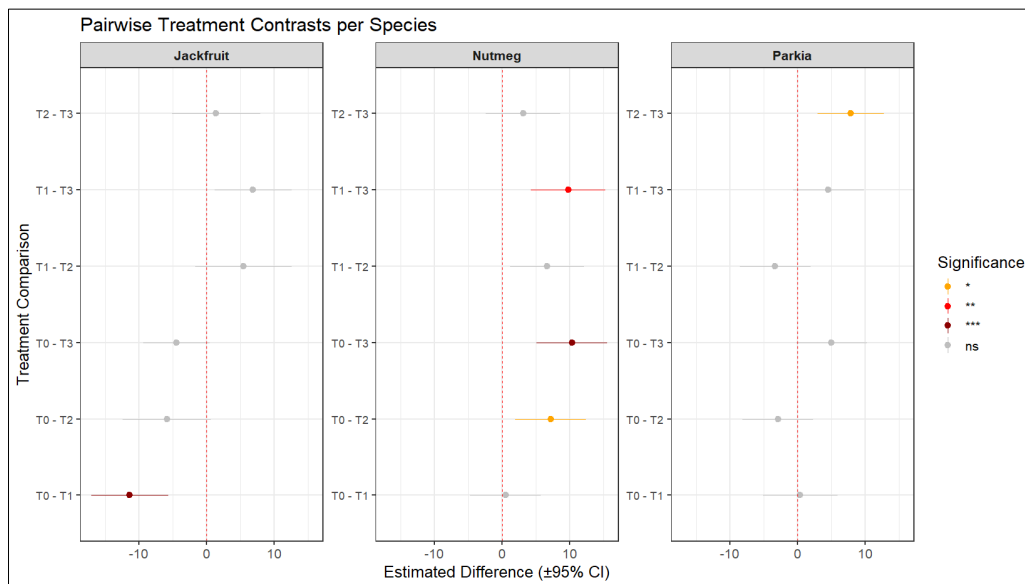


Figure 4. Tukey's post hoc test results

Table 2. Pairwise treatment contrasts by species

Contrast	Bitter bean (<i>Parkia speciosa</i>)	Jackfruit (<i>Artocarpus heterophyllus</i>)	Nutmeg (<i>Myristica fragrans</i>)
T0 – T1	-	T1 > T0	-
T0 – T2	-	-	T0 > T2
T0 – T3	-	-	T0 > T3
T1 – T2	-	-	-
T1 – T3	-	-	T1 > T3
T2 – T3	-	-	-
T2 – T3	T2 > T3	-	-

4. Conclusions

The findings underscore that the effectiveness of forest and land rehabilitation (FLR) interventions is highly species-specific, with jackfruit showing the strongest response to simple irrigation, nutmeg performing better under minimal intervention, and bitter bean benefitting moderately from plastic mulch combined with irrigation. These outcomes suggest that restoration programs should avoid uniform silvicultural practices and instead adopt species-tailored strategies to maximize ecological and growth performance. From a practical perspective, such differentiated approaches can improve the efficiency of FLR efforts in degraded landscapes like the HKM Bukit Sultan, Aceh Besar, while also enhancing community-based restoration initiatives. Future research should further investigate long-term effects of combined irrigation–mulching treatments, particularly under varying climatic conditions, to refine restoration guidelines and strengthen the resilience of socio-ecological systems.

References

- [1] Adharsh C J 2021 Weather extremes preparedness of nutmeg (*Myristica fragrans*) farmers in Kerala (Kerala Agric. Univ.)
- [2] Ajithkumar B, Kurien S, Rao V U M, Sreekala P P, Vishnu C and Sekhar E R 2015 *Agro Climatic Atlas of Kerala* All India Coordinated Res. Proj. on Agrometeorology, Kerala Agric. Univ., Vellanikkara, Kerala, 219
- [3] Demo A and Bogale G 2024 Enhancing crop yield and conserving soil moisture through mulching practices in dryland agriculture *Front. Agron.*

- [4] Elevitch C R and Manner H I 2006 *Artocarpus heterophyllus* (jackfruit) Species Profiles for Pacific Island Agrofor. 10 1
- [5] Hamad S 2023 Effect of different irrigation periods and mulching on growth of *Paulownia tomentosa* (Thunb.) Steud. seedlings Zanco J. Pure Appl. Sci.
- [6] Komarayati S 1995 Prospek pengembangan tanaman nangka ditinjau dari sifat arang dan aspek lainnya *J. Penelit. Hasil Hutan* 13 45–51
- [7] Kun Á, Simon B, Zalai M, Kolozsvári I, Bozán C, Jancsó M, Körösparti J, Kovács G, Gyuricza C and Bakti B 2023 Effect of mulching on soil quality in an agroforestry system irrigated with reused water *Agron. J.*
- [8] Machado D, Dourado M, De Freitas M, De Souza L, Da Silva E, Podadera D, Andrade C, Ferreira W and Guilherme F 2024 Organic mulching alters the soil microclimate, increases survival and growth of tree seedlings in restoration planting *For. Ecol. Manage.*
- [9] Madhava C K and Surendran U 2016 Study on factors influencing the adoption of drip irrigation by farmers in humid tropical Kerala, India *Irrig. Drain.* 10 348–364
- [10] Matsuda H 2024 Jackfruit (*Artocarpus heterophyllus* Lam.) grafting as affected by nitrogen fertilizer application to irrigation water *Sci. Hortic.*
- [11] Montgomery D C 2009 *Design and Analysis of Experiments* 7th ed (Hoboken, NJ: John Wiley & Sons)
- [12] Nugroho Y 2015 Aplikasi silvikultur intensif untuk pertumbuhan tanaman pengayaan pada lahan reklamasi tambang batubara *J. Hutan Trop.* 3 241–246
- [13] Spyroglou I, Skalák J, Balakhonova V, Benedikty Z, Rigas A G and Hejátko J 2021 Mixed models as a tool for comparing groups of time series in plant sciences *Plants* 10 362
- [14] Sun X, Zhao J, Wang G, Guan Q and Kuzyakov Y 2023 Fine root extension in urban forest soil depends on organic mulching *Agrofor. Syst.* 97 235–247
- [15] Pagliari P, Galindo F S, Strock J and Rosen C 2022 Use of repeated measures data analysis for field trials with annual and perennial crops *Plants* 11 1783
- [16] Gomez K A and Gomez A A 1984 *Statistical Procedures for Agricultural Research* 2nd ed (New York: John Wiley & Sons)
- [17] Yang K, Wang H, Luo L, Zhu S, Huang H, Wei Z, Zhu Y, Guo L and He X 2022 Effects of different soil moisture on the growth, quality, and root rot disease of organic *Panax notoginseng* cultivated under pine forests *J. Environ. Manage.* 329 117069
- [18] Zheng C, Wang R, Zhou X, Li C and Dou X 2022 Photosynthetic and growth characteristics of apple and soybean in an intercropping system under different mulch and irrigation regimes in the Loess Plateau of China *Agric. Water Manag.*